ELECTRICITY

FOR

BEGINNERS.

t

SHARPSTEEN'S

LESSONS IN ELECTRICITY FOR BEGINNERS.

43690 aa'

PUBLISHED BY
A. A. SHARPSTEEN,
BINGHAMTON, N. Y.,
1895.

PRESS OF BINGHAMTON REPUBLICAN.

PREFACE.

The following pages have been prepared for persons with a limited education who are desirous of getting a more thorough knowledge of the science of electricity as it pertains to electric lighting and power transmission.

An effort has been made to prepare the work in such a way that all the subjects treated can be very readily understood by almost any person who has a mind to try to understand them.

AUTHOR.

CHAPTER I.

INTRODUCTORY.

1.—The average stationary steam engineer thinks that he has got his hands full to keep his boilers clean and tight, and his engine or engines running smoothly, when all at once he has an electric-light plant saddled upon him. The old trouble with boilers and engines are of small import now, when compared with the new perplexities. All is new and mysterious. Fuses, switches, branch blocks, amperes, volts, electro-motive force, current, and many other terms are showered down upon him in torrents.

2.—Well, the only thing to do is to set about it and learn something of the new system of lighting. In connection with the wiring the fuses are possibly the first to give trouble, and it is very easy to get a wrong impression in relation to them.

3.—Great care should be exercised in connection with the fuses. "Why," the average man will say, "that part seems simple." All things are simple to the simple minded, but the doom of every structure lighted with incandescent electric light depends upon the fuses. Perfectly safe if wired well and fuses are right.

4.—You will often hear persons that have to do with electric lights say: "Well, that fuse won't go out again, I have put one in large enough to stay." If you should ask what was put in you might be informed that a piece of bare No. 10 B. & S. gauge copper wire was placed where possibly a 5 ampere fuse should be.

5.—The first thing that suggests itself to a person is: "What might be the result?" Well, one thing that might happen is, a person conversant with electrical work might discover the state of things and report the same to the inspector of the board of fire underwriters, the inspector might go to the employer and so represent things that the engineer might possibly lose his job. Fire underwriters are very exacting in relation to fuses.

6.—Oftentimes the supports for the wire become broken or the wire pulled from them; in such an event if the wire gets against the wood-work, and the insulation impaired, a current may pass from wire to wire through the wood sufficient to ignite it. These currents are sometimes called sneak currents If the fuse was just large enough to carry the load, the extra current ought to open the circuit.

7.—Where wires are concealed under floors and in partitions they sometimes come very close to combustibles, and if a fuse is large, controlling a 14 wire B. & S. gauge running to some outlet, in case the bare wires of opposite polarity come together, if the source of supply is of any size, and the loop long enough to make the proper flow of current, the 14 wire in the loop may get red hot, ignite the insulation, and set the building on fire. Some people tell about putting wires inside of conduit and then they surely are safe. It matters not if the conduit has a heavy iron covering, a wire can be heated red hot, and how long before insulation and iron will both be hot enough to set fire to wood-work?

CHAPTER II.

UNITS.

8.—We have progressed as far as we can along this line without getting some little knowledge of what this pressure and current is that is playing such a peculiar part in these wires and fuses. Possibly there are the words amperes and volts on the machine, and 110 volts may be marked on every lamp, what does it mean? Did it ever occur to you that you were establishing standards or units in your minds by which to measure things about you?

9.—The people of all grades of civilization have units of measurement, but the higher the civilization the more ado there is about what the units are based upon, and the more convenient the arrangement for their use. You have the whole day of 24 hours divided, and we will say here for convenience that your unit of measurement or your "stick" by which you measure the day is the hour, and for many uses the hour is too large, and then you divide the hour into sixty parts and call these parts minutes.

10.—You don't have to take the dial off a clock in the morning and lay out your work so as to get back home at noon, but you have the dial fixed in your mind, and by occasionally looking at a clock or watch you get around at the proper time, and have got done about what you planned in the morning. With a little study and thought the electrical units will become just as familiar to you as the divisions of time. After you once get a start in the right direction you will keep adding to your knowledge and use of the electrical units when you least expect to.

11.—There is a something that pushes the current of electricity along. The unit or measuring stick by which this pressure is measured is called a volt. There is something that tends to hold the current back, and the unit or measuring stick by which this resistance is measured is called the ohm. When a circuit is closed and the pressure is applied there is a something on the move in the wire; this something passing through the wire is commonly called a current of electricity; this current of electricity may be large or small, and the unit or stick by which it is measured is called an ampere Volt, Ohm and Ampere were the names of three celebrated men: no other significance is attached to their derivation.

CHAPTER III.

VOLT.

12.—The battery that is much used for telegraph work and which almost every person has seen, has a pressure slightly more than one volt; it is called by some the Daniel Battery, by others the Blue-Stone Battery, from the blue sulphate of copper that helps to make up its solution. This battery has a pressure of about one volt, and it takes very nearly 110 of them to get a pressure sufficient to light a 110-volt incandescent lamp. Don't understand from this that 110 of these cells would light any 110-volt incandescent lamp that you might have, as there are other things besides the voltage to consider which we will speak of later.

13.—On a machine which is built to run 110-volt lamps it matters not if there be one lamp on the machine or 100 if the mains are large enough to carry the current without any loss; the pressure is the same for the 100 as for the one; this is shown by the voltmeter on the switchboard. It is understood that the machine is large enough to carry the lamps. The same thing might be said of a whole city; the pressure for one or 5,000 lamps would be the same if they were carried by a direct system.

or came direct from the machines as in the average factory, but for long mains or circuits and only 110-volts pressure the wires or mains would have to be very large, which prohibits the use of such a system for city lighting.

14.—The street railroad companies use a pressure of 500 volts for their roads. This pressure it is claimed will not kill a person, but is very painful if the conditions are right, and a person is subjected to the pressure.

15.—If the railroad people could use a higher voltage they could use much smaller mains, but people, especially the motormen, are so liable to get the full pressure that the companies have to be content with the low pressure. Most of the companies now use for incandescent work at least a thousand-volts pressure; this pressure is made much lower by what is called transformers, before it enters buildings for lighting.

16.—A ten-light arc machine has a pressure of about 500 volts when working with all the lamps on. A fifty-light machine has a pressure of about 2,300 volts. Some arc machines have a pressure or voltage sufficiently high to burn 100 arc lamps at one time. All arc currents mentioned are considered as 10 ampere. Such a machine would have a voltage of about 4,600 if the lamps were 2,000-candle power.

17.—As high as 11,000 and 25,000 volts we hear talked about now for power transmission plants.

One arc lamp takes about 45 volts; so a machine running one arc lamp has a pressure of only 45 volts, for two lamps 90, &c. In speaking of pressure in relation to a machine running incandescent lamps, we said that the pressure was the same for one or 100 lamps if the mains were large enough.

18.—With the pressure or voltage on a regular arc machine the reverse holds true. For every lamp that is added, the pressure has ~~got~~ to be raised if the current is kept up to the proper number of amperes. One volt pressure would force current enough through the coils of the average bell to make its magnets pull quite hard.

CHAPTER IV.

OHM.

19.—After the dynamo has run for some time, you can feel some warmth, if you place your hand on the field coils. This warmth usually comes from the current of electricity passing through the wire wound on the fields of the machine, and indicates that there is a resistance there of some kind which transforms or turns this passing current into heat. When a thunder-storm is on, this problem of resistance and heat is very nicely illustrated.

20.—The enormous voltage that is made up in the clouds pushes the electricity through the atmosphere, and the resistance of the atmosphere is so high that the electricity not only makes the atmosphere warm but white hot, and we call the white places that we see lightning. The incandescent lamp has a resistance that will permit current enough to pass to make the filament of the proper heat to emit light. As mentioned above, the word that is used in speaking of this resistance is called the ohm. 1,000 feet of No. 10 B. & S. Gauge copper wire, has a resistance slightly more than one ohm.

21.—1,000 feet of No. 20 B. & S. Gauge copper wire has about $10\frac{1}{2}$ ohms resistance. 1,000 ft. of No. 30 B. & S. Gauge copper wire has a resistance of about $107\frac{4}{10}$ ohms. 1,000 ft. of No. 1 B. & S. Gauge wire has a resistance of about $1\frac{1}{3}$ ohms. A 110-volt, 16-candle-power lamp has a resistance of about 180 ohms.

22.—No two metals or substances of the same length and cross-sections have the same resistance. Of the metals, silver puts the least resistance in the path of a current of electricity; copper comes next; soft iron has about seven times as high resistance as copper.

23.—Sometimes people form the idea that a current of electricity cannot pass through rubber and certain other materials that are called non-conductors. This is a mistake; all metals and substances will permit of a current of electricity passing through them, but their resistance is so very high that the current of electricity that passes is so small that in practice it is often considered as no current at all.

24.—In speaking of these very high resistances, the word meg-ohm is used, which means a million ohms. It is a common thing to hear persons speak of 25 or 50 or even 500 meg-ohms when they are talking of insulation.

CHAPTER V.

AMPERE.

25.—There are currents of electricity infinitely small and others enormously large ever about us when we are on the streets of a city, and the way they are usually thought of by the practical electrician, the scientist possibly as well, is in amperes or fractions of an ampere.

When a person that is accustomed to working at piping for water conveyance and tinkering the same when out of repair, looks at a system of piping that is filled with water or steam under pressure, he thinks of it in a much different way than he would if he knew it was empty. The same is true of a person connected with electrical work; when he gets where a number of wires can be seen that are conveying currents of electricity, the wires are thought of in a much different way than they would be if they were known to be "dead," or there was no current passing through them. This unit ampere is one much used, and we should try and get a proper conception of it.

26.—Milampere means a current one-thousandth as large as an ampere, and is used in making tests of various kinds, and in medical work. In other words, if the ampere was divided into one thousand parts, one of the parts would be a milampere.

27.—If a warehouse or isolated plant be properly wired, a person may watch the volt meter or instrument that shows what pressure is being carried, and it stands about the same regardless of load. The pointer of the ammeter or instrument that measures the amperes swings around and indicates more amperes as the load gets on.

28.—Two lamps run from a 110-volt machine will make a difference of about one ampere. Thus instead of the voltage or pressure increasing the amperes increase as the lamps or motors go on.

29.—It was mentioned that the voltage increased as the arc lamps were put on a regular arc-light machine, and if an ammeter should be in a circuit of an arc-light machine which was regulated closely, one would notice that the ammeter needle would point to one place the whole time, regardless of the number of lamps on the machine.

30—We are then to understand that the amperes or amperage increases as the load increases on an incandescent machine, and the voltage remains nearly the same; hence an incandescent machine is called a constant voltage machine.

31.—That the volts pressure increases as the load increases on an arc machine, and that the current or amperes remain the same, hence an arc–light machine is called a constant amperage or constant-current machine.

CHAPTER VI.

WATT.

32.—The watt is the rate of doing work or the unit of power similar to the unit horse-power used in mechanics. There are 746 watts in one horse-power.

How often we hear persons call incandescent lamps, 3 watt lamps, 3½ watt lamps, etc., and in selling electric power and current for electric lights we hear watt hours spoken of.

33.—It is quite a common thing now to hear dynamos rated by kilowatts. The number of kilowatts determines the size of the machine. Kilowatt means a thousand watts, hence a five-kilowatt machine means a five-thousand-watt machine.

34.—If we know the number of amperes of current and volts pressure of a machine, we multiply one by the other and divide the product by one thousand, and the result that we may get will be the kilowatts of the machine. As an example, if the machine has wire on its armature large enough to carry 100 amperes of current, and develops a pressure of 110 volts with full load, we multiply 100 amperes by 110 volts and get 11,000 watts. The machine then would be a 11,000-watt machine, and if we divide the 11,000 watts by 1,000 we get 11, which means that we have an 11-kilowatt machine.

35.—If we should want to find what the output in horse-power of any dynamo was of which we might know the volts, pressure and amperes, all that is necessary to do is to get the watts and divide the same by 746. An example:

A 500 volt and 200 ampere machine.
500×200=100,000÷746=134 H. P.

There is something more to be considered in relation to this unit watt before we have a proper conception of the same.

36.—We may get into a boiler house of an electric-light station and look at a number of tons of coal and say that there is energy enough stored up there to do a certain number of watts of work, or in other words so many horse-power of work, and then we commence to compute or figure on the problem. We find the dynamo is carrying 35 amperes of current at 1,040 volts pressure. 35 amperes × 1,040= 364,000 watts or about 49 H. P. We have 49 H. P. and a certain pile of coal in the boiler house; two hours later we have 49 H. P. and much less coal in the boiler room.

37.—Thus far in our problem we have demonstrated that the coal pile keeps getting smaller, but we are still developing 49 horse-power.

There is one thing passing that we have not taken into consideration, and that is time. 49 H. P.

for one hour's time takes a certain amount of coal. Now we commence to get out of the mist.

38.—When speaking of doing work or selling energy to do work, we must always consider time. The water may lie above a mill dam, and down near the water wheel there may be great pressure, but there won't be any work done or energy consumed until the water commences to move through the wheel, and if the machinery is belted to the wheel and the wheel runs for an hour a certain amount of work is done, and a certain amount of water under pressure has passed through the wheel and is no more above the dam.

39.—We hear lamp hours spoken of, meaning possibly one 16-candle-power lamp burning for a certain number of hours, but a person can hardly find two 16-candle-power lamps taking exactly the same amount of current; so a 16-candle-power lamp hour is a poor measuring stick or unit to measure by. And then again the pressure may vary. For instance, a person may be near the station and get 115 volts pressure when others are getting but 110, hence the former is getting much more energy than he is paying for. Where a person buys electrical energy by the watt hour and gets the same through a good recording watt meter, he pays for the energy he gets—that is, the volts pressure and amperes current are both taken into consideration.

40.—Now, understand that in selling electrical energy for any purpose by a watt meter, time is always considered with volts pressure and amperes current. Also remember that in selling lamps, motors and dynamos, only volts and amperes are considered.

41.—When a three-watt 110 volt 16-candle-power lamp is spoken of it means a lamp that will take three watts of energy to keep it up to rated illuminating power for each candle of light; hence three watts × 16-candle-power would make a product of 48 watts for one 16-candle-power lamp, and since the volts pressure that the lamp requires is 110, we divide the 48 watts by 110 and get $\frac{48}{110}$ of an ampere.

Now, we have found that in order to get watt hours we must multiply volts pressure by amperes current, and again by hours of time, hence volts × amperes × time in hours=watt hours. To get watts we have found that we are to multiply volts by amperes, and when we have watts and voltage given and want to get the amperes, we are to divide the watts by the volts pressure.

42.—As an example we will consider an 880 watt machine having a voltage of 110. To find the amperes we divide the 880 watts by 110 volts and get eight amperes, and if we have an 880 watt machine and its amperage is 1.8 or $1\frac{8}{10}$, we divide 880 by 1.8 and get 500 volts very nearly.

CHAPTER VII.

OHM'S LAW.

43.—Thus far we have spent our time in getting our thoughts in some order so that we can concentrate them.

Two persons may work side by side with the same tendencies and mental abilities. The one may be systematic in thought, and day by day grow in mental vigor and strength in a way that will be surprising, while the other who does not work mentally with some system, will possibly do more hard thinking, but never have any practical idea about what he has been working and thinking, and never move up to a higher plane of thought and action.

We have gone over the subjects treated in a very simple way, but should have acquired some foundation upon which to build something a little more substantial.

44.—We will next undertake to study out what is meant by Ohm's law, and how to use the same to help us think aright about electrical matters.

45.—The term Ohm's law may sound to us as if it might take some profound mind to comprehend it, but such is not the case. Of all the simple things to understand this is one of the simplest, if only we will give it a little thought.

46.—The question as to what use Ohm's law is may arise, and we will say right here that it helps us to comprehend many things, the simplest of which are: When we have volts pressure of a machine or batteries, and the ohms resistance of our copper wire or circuit, we can tell what current is going to flow. If we have volts pressure and know the amount of amperes current that we want to pass through any circuit, we can tell just what size wire to put in or just the ohms resistance to put in to get the desired result.

47.—If we know the ohms resistance of any circuit and the amperes current that we want to pass through said circuit, we can determine the number of volts pressure that is necessary to use.

48.—To try and make the case plain we will consider that we have got a mill dam 20 feet high, and that we can bore holes in it. If we make a one-half inch hole, say two feet from the bottom of the dam, we will get a certain size jet of water through the hole; if we put in the second hole same size, same height, we get two times the water we did first. The head or pressure of the water we can compare with our pressure in electricity. When the dam is perfectly tight the resistance is so high that no water can pass through, hence the dam is similar to resistance in electrical parlance. If we remove some of the resistance by making a hole in the dam, water flows; hence we may compare the water flowing to the current of electricity passing through a wire.

49.—When we start up our dynamo and disconnect the outgoing circuit if the brushes are down, field circuit closed, and we have the proper speed, with a shunt machine we get a pressure, but there is no current flowing outside the machine, and we ask ourselves "Why?" and the answer is: "The machine is surrounded by a dam that keeps the current of electricity from flowing. Electricity won't pass through the atmosphere or wood about the machine, because, like the dam to the water, the air and the wood won't let it go through. Now if we cut a hole in this dam of air by putting a piece of copper through it, we have a path along which the current will pass.

50.—To get back to Ohm's law, which is written thus:

$$\text{Current flowing} = \frac{\text{Volts pressure.}}{\text{Ohms resistance.}}$$

or, to write the whole thing out: Current flowing is equal to the volts pressure divided by ohms resistance.

We will suppose that the dynamo just mentioned has a pressure of 100 volts, and when the pressure is up, we put 100 feet No. 30 B. & S. gauge wire, which has a resistance of about 10 ohms, from the positive to the negative brush, then we try and find from Ohm's law how much current is flowing in this hole that we have cut into our dam.

$$\frac{\text{Volts pressure of the machine 100.}}{\text{Ohms resistance of wire 10.}} = 10 \text{ amperes current.}$$

51.—Now if we put another piece of wire 100 feet No. 30 B. & S. gauge from pole to pole of the machine we will have, at first thought, many would say, "20 ohms," because one piece has a resistance of 10 ohms, two pieces would have twice 10 ohms, or 20 ohms resistance. This, on reflection, we will find is not true, when we put the second piece of copper from pole to pole we double the size of the copper, we have a cross from brush to brush, hence instead of a No. 30 we have about a No. 27 wire, and instead of 10 ohms we will have about 5 ohms, hence we have cut the resistance down one-half, and our problem becomes:

$$\frac{\text{Volts pressure } 100}{\text{Five ohms}} = 20 \text{ amperes.}$$

It is just the same as cutting an inch hole in our mill dam and getting a certain flow of water. Now if we put another inch hole beside the first we don't raise the resistance or obstruction to the water, but we lower it and make twice the size opening, hence twice the amount of water flows.

52.—Possibly we have been in a large crowd of people waiting to get through a small gate. If a second opening was made by adding another gate, twice the number of people would pass; it would be cutting down the obstruction, not making more of it.

53.—The copper put from pole to pole of the machine is similar to the gate, one piece will let a certain amount of current flow, two pieces of the same gauge will let double the amount of current flow, hence the obstruction or resistance to the current has been lowered.

54.—Having illustrated Ohm's law so that almost any person can get an idea of what it is used for, we will become more brief and try and apply it somewhat. This is how we usually see it written:

$$C = \frac{E}{R} \text{ or we might put it thus: Amperes} = \frac{\textbf{volts}}{\textbf{ohms}}$$

C stands for current in amperes.

E for pressure, or E. M. F., which means electro-motive force in volts.

R for resistance in ohms.

Then we can transform the formula and put it thus: When we have volts and amperes and want to find ohms, ohms or $R = \frac{E}{C}$, and when we have C and R and want to find E, we put it thus: $E = C \times R$.

It may make this transformation plainer to illustrate it with figures, thus:

$$2 = \tfrac{6}{3}, \text{ or } 3 = \tfrac{6}{2}, \text{ or } 6 = 2 \times 3.$$

55.—Examples:

[*a*] A dynamo with a pressure of 110 volts generates a current of 100 amperes when its load is on. The 110 volts is shown by the volt meter on the switchboard, and the 100 amperes is shown by the ammeter on the switchboard. What is the resistance of the circuit and lamps when the machine is generating the 100 amperes?

By Ohm's law $\frac{110 \text{ volts}}{100 \text{ amperes current.}} = 1\frac{1}{10}$ ohms.

[*b*] Instruments on switchboard show a pressure of 110 volts and ½ ampere; what is the resistance of the lamps and circuit?

[*c*] Instruments on switchboard show a pressure of 560 volts and amperage of 500; what is the resistance of external circuit?

[*d*] The resistance of a given circuit is two ohms with all lamps turned on, and the voltage is 110, what is the amperage?

[*e*] The resistance of a given circuit is five ohms with lamps on, and the amperage or current is 100; what is the voltage?

[*f*] The amperage of a given circuit is 10 with load on, and the voltage 5,000; what is the resistance?

[*g*] An electric bell with a resistance of three ohms is put in circuit with a grove cell of battery that has an internal resistance of $\frac{4}{10}$ of an ohm and a voltage of $1\frac{9}{10}$; what current will flow through bell and battery when the circuit is closed, assuming that the wire connecting bell and battery is so short that its resistance is nil?

[*h*] No. 10 B. & S. gauge wire has a resistance of about one ohm to the 1,000 feet. If we put 1,000 feet of this wire in circuit with a 110 volt machine of large capacity, what current will we get?

[*i*] Assume we have 70 pounds No. 23 copper wire B. & S. gauge that we intend putting on the fields of a 500-volt moter; what amount of current in amperes will pass through the wire, the resistance of the wire being about 950 ohms?

CHAPTER VIII.

SERIES CIRCUITS.

56.—How often we hear persons speak about electric lights or motors being put either in series or multiple. The multiple circuit is treated under No. 86. Almost all the arc-light circuits of the world are what are called series circuits.

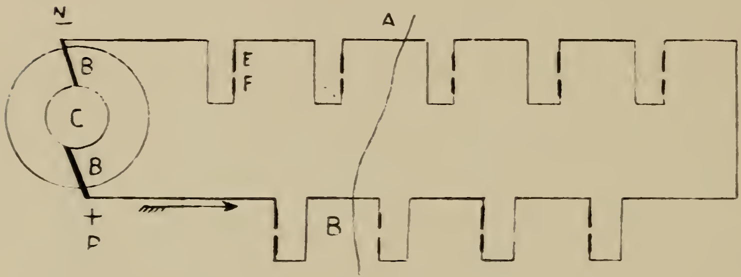

FIG 1

57.—By tracing the wire around in the cut it will be seen that the whole current passes through all the lamps, hence we might define a series circuit as one in which the whole current passes through every foot of wire, and every piece of apparatus put in circuit.

All have to let the same current pass through them, with these exceptions, in case of leakage as from A to B by a wire across the circuits or from faulty construction some of the current may pass across and not go through the lamps beyond the trouble.

Another exception is in the lamp where a small portion of the current usually passes around the carbons through what are called the shunts or fine wire magnets that are used in the regulation of the arc in the lamp. Practically speaking, the whole current in the arc lamp passes through the carbons.

58.—All the current that may pass through the fine wire magnets in the arc lamp is a dead loss of energy, as far as light is concerned. This current is usually very small. One good feature of the series system is that the single wire can be run along one street, and back some other street, or a circuit can run hither and yon through a whole town, feeding lamps at any point on said circuit.

59.—One of the great redeeming features of the series system is that a large amount of energy can be transmitted over a large area with a small amount of copper.

60.—As mentioned farther back, with a series circuit the pressure increases as the lamps or motors are put in the circuit. It usually takes about 45 volts on a 10 ampere circuit to produce a nominal 2,000-candle-power light. If we switch in lamp No. 1 in the cut, and consider that all the rest are switched off, if the wire is No. 6, B. & S. gauge and very short, there will be a difference of about 45 volts at the binding posts of the machine.

61.—The pressure at the brushes, if it be a series machine, will be much greater since the 10 amperes of current has got to be forced through a great length of wire on the field magnets. There are series dynamos as well as series circuits, but the series circuits we are considering now.

When we switch in lamp No. 2 there will be a difference of 90 volts at the machine. By adding No. 3 the pressure will come up to 135 volts, and so on until the whole number is on, but we have learned that the current remains the same, hence this is a constant-current circuit.

CHAPTER IX.

LOSS OF ENERGY IN CONDUCTORS.

62.—This brings us up to another important subject that we must understand in our reasonings about electrical matter, and since we have acquired some knowledge of the electrical units, we can get a very clear idea of it.

63.—We have found that any conductor will offer more or less resistance to the current of electricity that may pass through it. This resistance turns a portion of the current passing into heat, and we usually consider that such amounts of energy as are turned into heat are wasted, hence we call it a loss of energy.

64.—This loss of energy is directly proportional to the square of the amount of current in amperes. To make it more plain, if we have two arc circuits each five miles long, and No. 1 circuit is made up of No. 6 copper wire, B. & S. gauge, it will have a resistance of about 11 ohms. To force a current of 10 amperes through a resistance of 11 ohms, will take, according to ohms law, 10 amperes multiplied by 11 ohms resistance, equals 1,10 volts.

65.—We learned farther back that volts multiplied by amperes gave us watts, and watts showed us what amount of energy was being consumed at any time when current was passing, hence 110 volts multiplied by 10 amperes gives us 1,100 watts. We are to understand then that more than one horse-power of energy would be consumed in the wire alone, when a current of 10 amperes was passing through five miles of No. 6 wire, B. & S. gauge.

66.—No. 2 circuit we will consider is composed of No. 9 copper wire, B. & S. gauge, five miles of which will have a resistance of about 22 ohms. According to ohms law, to put 10 amperes through resistance of 22 ohms will take 22 times 10 or 220 volts, and 220 volts times 10 amperes gives us 2,200 watts, just double the amount of energy that was used up in the No. 6 wire; hence we have demonstrated that the loss of energy in a conductor with a certain amount of current flowing is doubled if we double the resistance, or as we said in the commencement of this explanation, that the loss is directly proportional to the resistance.

67.—Examples:

[*a*] What is the loss of energy in watts in a circuit of 1½ ohms and 12 amperes of current?

[*b*] What is the loss of energy in watts in a telegraph circuit of 10,000 ohms .02 or $\frac{2}{100}$ of an ampere current?

[*c*] What is the loss of energy in watts in the mains between machine and first lamp, feeding 400 16-candle-power lamps, ammeter indicating 200 with load on? The size of the wire is such that there is a loss of five volts in the two legs of the mains.

CHAPTER X.

PRESSURE AND LOSS OF ENERGY.

68.—We will now demonstrate that increasing the pressure in any circuit will not increase the amount of energy lost as long as the current and resistance remain the same.

69.—As an example we will take a case where a 50-arc light machine 10 amperes of current is at night-time furnishing the necessary electrical energy to burn 50 arc lamps in a town five miles from the machine. Understand that there is five miles of wire in each leg of the circuit without any lamps, thus:

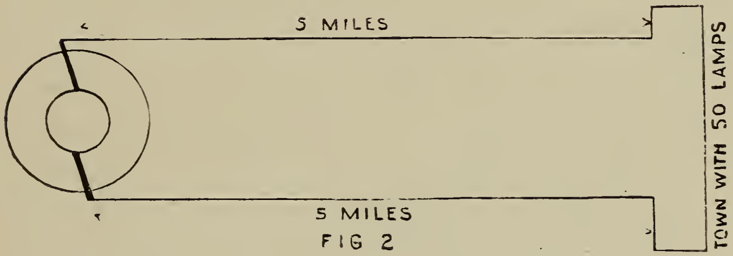

FIG 2

70.—Early in the evening there are 25 of these lamps turned on in the stores, &c., then at the terminals of the machine we will have a pressure of 45 × 25=1,125 volts to force the current through the 25 lamps + 217 volts to force the current through the 10 miles No. 6 wire + 60 volts used in forcing the current through the circuit in the town = 1,402 volts pressure at the machine. What we want to find out now is just the amount of energy lost in our ten miles of wire between the towns when these 25 lamps are on, and we have 1,402 volts at the machine.

Ten miles of No. 6 copper wire, B. & S. gauge, has a resistance of 21.7 ohms, and according to ohms law, it will take 10 amperes × 21.7 ohms to get the voltage necessary to force the 10 amperes through the 10 miles of wire, which will give us 217 volts. Now to get the watts of energy lost, we will have to multiply 217 volts × 10 amperes, which will give us 2,170 watts, or when divided by 746 will give us 2.9 horse-power lost in this ten miles of wire when the electrical energy is passing through it at a voltage of 1,402.

Later in the evening the street lamps are switched in circuit and the pressure at terminals of the machine comes up to 1,402 volts + 1,125, the voltage necessary to force the 10 amperes current through the additional 25 lamps = 2,527 volts.

71.—Now the pressure of the current passing through the five miles of wire between the towns has almost doubled, but we lose no more energy in it than before, for we have the same resistance in the wire between the towns, and the same amount of current flowing, hence the amount of energy lost is the same for the 2527 volts strain as for the 1402 volts strain.

72.—Hence we have demonstrated that increasing the pressure of the current passing through a wire does not increase the loss of energy in the wire. This makes plain to us why it is that electrical engineers are ever trying to devise some scheme by which they can transmit electrical energy at high pressures and still have it safe to handle and convenient for use. If there was no limit to the voltage large amounts of electrical energy could be sent for thousands of miles on very small copper wires, or even iron wire.

Year by year the devices are getting better, and the voltages raised, hence the problems of power transmissions are getting more practical. Here is a field for almost any man to work into, as it is a large and promising one.

CHAPTER XI.

INCREASE OF CURRENT AND LOSS OF ENERGY.

73.—Thus far we have demonstrated that if we double the resistance with a certain amount of current flowing we double the amount of energy lost in the conductor if the amount of current remains the same in both cases. We have also demonstrated that increasing the pressure or tension of the current passing through the wire does not increase the loss of energy in said wire as long as the resistance and amperes remain the same.

74.—When the current is increased, the loss of energy increases very rapidly, which will now be demonstrated.

75.—By using circuit No. 1, which was five miles of No. 6 wire B. & S. gauge, we have a resistance of 11 ohms, and it was demonstrated that to force 10 amperes of current through this five miles of wire of 11 ohms resistance required a pressure of 110 volts, or according to ohms law, when we have ohms and amperes to find volts we multiply the ohms by the amperes, thus: 11 ohms multiplied by 10 amperes of current gives 110 volts; to get the watts, 110 volts just found multiplied by 10 amperes of current gives us 1,100 watts. This is for

10 amperes through five miles No. 6 wire or 11 ohms.

76.—Now we will increase the current to 20 amperes and see what results we get: 20 amperes multiplied by 11 ohms gives 220 volts. To find watts, 220 volts multiplied by 20 amperes gives us 4,400 watts.

77.—It is plainly demonstrated that when the current is increased and the resistance remains the same, the loss of energy increases very rapidly. It should be observed that the pressure had to be doubled as the current was doubled, so that the actual loss in watts is four times as much for the 20 as for the 10 amperes.

This makes it quite plain why the Electrical Engineer is ever trying to keep down the amperes current all that it is possible.

78.—It is not only a question of loss of power, but the trouble that arises from the loss of pressure is very great.

CHAPTER XII.

CARRYING CAPACITY OF WIRES.

79.—When the beginner commences to make calculations in determining sizes of wire for carrying any number of incandescent lamps, the safe carrying capacity is the first thing to think of. On referring to tables he might find that six amperes was considered safe for a No. 14 wire, B. & S. gauge. He may have 12 or 13 lamps that he wants to wire in some outbuilding, say about 1,000 feet from the mains carrying current for main building or from the dynamo. The 12 lamps are wired and connected up, current turned on, but for some reason the lamps don't seem to burn properly—they are dim. Now there is a terrible thinking set up; the lamps are changed, the fuses changed, but all to no avail—the lamps will not burn brightly.

80.—After inquiry or close observation the trouble may be found, when the beginner is impressed with the fact that there is something besides carrying capacity to be considered, and this something is commonly called "drop," or loss of pressure. We will find by Ohm's law what pressure the lamps had at the end of the 1,000 feet of wire when the lamps were all burning.

81.—The resistance of 1,000 feet of No. 14 copper wire B. & S. gauge is about 2.59 ohms. Multiplying 2.59 by 2 because there are two lengths, or one out and another back, we get 5.18 ohms. Twelve good lamps 16-candle power of 110 volts will use about ½ ampere to the lamp, or six amperes for the 12 lamps.

82.—We now have amperage and resistance, and according to Ohm's law if we multiply them together we get the volts, hence 5.18 times six amperes gives us a result of 31.08 volts. Thus we have found that it will require over 31 volts to force six amperes of current through 2,000 feet of No. 14 wire, B. & S. gauge.

83.—The voltage of the dynamo being 112 at the machine or switchboard, since the pressure is usually carried a little high there for the reason that there is always some loss in a circuit.

84.—Well, with 112 volts at switchboard, less 31 volts that was necessary to force 6 amperes of current through 2,000 feet No. 14 wire, we would have 81 volts pressure at the lamps. This demonstration makes it plain why the lamps in outbuildings did not burn properly.

85.—There are almost as many formulas for computing sizes of wire as there are hairs in a man's head, but they are of very little use.

86.—A good wiring table for 50 and 110 volts is convenient for reference when a person is daily computing sizes of wire for buildings.

87.—With an isolated plant, where the building is not very large, or the wire is to start from the switchboard or very near it, three per cent drop is all right with the average load, but when the source of the current is far away and there has got to be some loss in the mains and transformers, the house wiring should not have much drop for good work.

88.—It is a common thing to find a difference of ten per cent in the voltage between one lamp on and all lamps on in buildings lighted either by central stations or isolated plants. This is a very bad state of things, and should always be avoided for permanent work.

89.—If one gets Ohm's law well fixed in his mind it is an easy thing, with the use of a proper wire table, to determine the wire sizes for any distance and any number of lamps.

90.—A person should always know the drop or loss of voltage before he commences to compute the sizes of wire for a job.

91.—Examples:

A section of a factory is to be wired for 18 lamps; the middle of the room or section is, along the paths the wires must take, about 100 feet from the switchboard or machine, drop three volts, voltage 110, lamps will take about ½ ampere each.

If a wiring table is handy it will be found that about No. 12 B. & S. gauge is the size, and No. 12 has a resistance of 1.5 ohms to the thousand feet; 200 feet, or 100 feet each way, would be ⅕ of a thousand;

1.5 divided by 5 equals .3 ohms resistance, multiplied by 9 amperes, the current taken for 18 lamps, equals 2.7 volts, or very nearly the three volts.

92.—Commercial copper has a higher resistance than the copper from which these tables were computed, hence we are on the proper side. Practically we might be a little high rather than low if an actual test was made with the wire in place, as sometimes the copper runs a little small, and in putting it up more is used than usually one thinks; so if a person is contracting to have a certain drop and wants to be on the safe side; the copper must be put in a little large.

CHAPTER XIII.

MEASURING WIRES.

93.—Before we commence computing and determining wire sizes to any extent, it is essential that we should know something ubout Mils. Circular Mils, &c.

94.—The inch and foot are very convenient in measuring such things as stone and lumber, but when they are used for measuring wire, things change materially. The inch is too large for diameters and cross sections of wires, and too small for lengths, hence we might hear a person say:—"We used on the fields of that machine wire about 11 mils diameter and five miles long."

95.—The results that have come about are these: For measuring diameters and cross sections of wires the inch has been discarded and the word mil used, which is the one-thousandth part of an inch.

96.—To a person who has never used a micrometer caliper it seems like folly to speak of a thousandth part of an inch. When we look at a steel scale divided into 64ths we make the remark that it is hard to read and determine sizes even to 64ths. This is true; but it is much easier to read thousandths of an inch with the caliper than it is 64ths with the scale. In working mica and computing sizes of wire, the mil means dimensions that can be understood just as plainly as the lumberman understands the inch.

97.—If we get the proper understanding of the way in which the dimensions of wires are to be computed, it will save us many a muddled thought. The whole thing is very simple, but there are but few in the electrical business that seem to understand it.

98.—Diameter is the distance across a circle; radius is the distance from the circumference to the center, or just one-half the diameter; thus A B is the diameter of the circle in figure 3, and C D the radius.

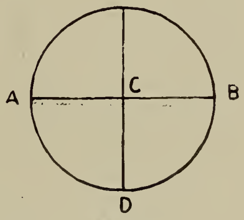

FIG 3

99.—We must understand that diameter and radius are straight lines. When sectional area is spoken of it means the whole surface of the section, or, in other words, if we cut the end of a bar of metal square off so as to make the cut surface at a right angle to the side of the bar, this cut surface will be the sectional area of said bar, be it a square, flat, or round bar.

100.—If we have a piece of two-inch round iron and we are asked the diameter, and if we are not sure what it is we can put a rule across the end and soon determine, and half the diameter is the radius. If some person asks us what the sectional area is in square inches of the same piece of iron, then the question is not so easily answered.

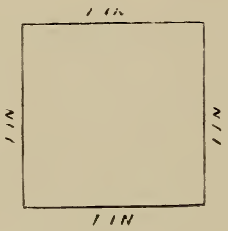

FIG 4

101.—We must get in the habit of thinking of wires by their sectional areas, or, in other words, by their actual size and weight. Round bars increase in weight and sectional area just in proportion to the square of their respective diameters. To square a number means to multiply it by itself, thus the square of the number 2 is 2x2, or 4; of 10 is 10x10, or 100; of 2½ is 2½x2½, or 6¼. A square inch of iron means a piece of iron an inch square, or an inch on every side, as in Fig. 4. A piece of round iron with a sectional area equal to one square inch has a surface across the end more than one inch in diameter.

102.—We will consider that we have a number of bars of round iron one foot long, of which we want to get the comparative weights. A, the smallest one, we will say has a diameter that will give an inch sectional area; B, another bar, is two inches in diameter, and to get the weight and sectional area compared to the first, we square its diameter and have 2x2, or 4. Hence we have found that we have four times the sectional area and four times the weight as with the inch bar.

[C]. With a bar four inches in diameter we would have the square of 4, or 4x4, which is 16, or sixteen times as much iron as in the first, or inch bar.

103.—It is very fortunate that the weights and sectional areas of circular bodies are proportional to the squares of their respective diameters, especially so for persons engaged in the electrical business.

104.—By looking at the wire table we find that opposite the gauge number in column one are numbers giving the diameters of all the different gauges or sizes, in mils, or in thousandths of an inch. Since the sectional area of a wire is proportional to the square of its diameter, we can get the sectional area, or actual size, of the wire in circular mils by multiplying the number of mils by itself.

105.—No. 30 wire we find has a diameter of 10 mils. To get the sectional area we square this 10 mils thus: 10x10 and get 100. Now this means that a No. 30 wire B. & S. gauge is equivalent in size to 100 wires one mil in diameter, or, in other words, has a sectional area of 100 circular mils. A No. 10 wire B. & S. gauge has a sectional area of 10381 circular mils, or is equivalent in size to 10381 wires one mil in diameter.

CHAPTER XIV.

MULTIPLE CIRCUITS.

106.—Under No. 56 we spoke of series and multiple circuits. The series circuit was there discussed, but, for good reasons, the multiple circuit was left until now. In the early days of electric lighting the linemen and others connected with the electrical business soon got the idea of putting up arc lamps, as only one size wire was used throughout, as there was always one quantity of current, either ten or twenty amperes. The 10 ampere people used No. 6 wire, B. & S. gauge, and the 20 ampere people No. 4 wire, B. & S. gauge. When a station was started, as a rule, they held to either the 10 or the 20 ampere current, and even if both kinds were used the linemen knew the two kinds of circuits and knew the sizes of wire to use.

107.—When an incandescent machine was put in and the multiple circuit was to be run, then things changed, and the poor linemen were troubled. The shrewdest of them would grasp at every straw of information; but oh, what a muddle and mystery when they heard of drop, ohms, sectional area, and found that the size of wire could only be determined by computations for every lot of lamps wired.

108.—Many men learned the business "parrot fashion" by working with skilled men, and if they got their training by working on 110 volt circuits, possibly later they would get into the employ of people about to use 52 volt lamps, and the result would be that all the wires used would be too small.

109.—What we mean by "parrot fashion" is this: a helper who had no theoretical training, in working with a skilled wireman would get a knowledge of about the size wire that was necessary for certain numbers of lamps with the voltage that was to be used where they were working. The helper would conclude that these same sizes of wire would do for any lamps of same candle power.

110.—These notions of linemen have been the cause of the loss of many a customer for the electric-light people, and the reason why a great many incandescent plants have not earned dividends.

111.—When a series circuit is spoken of we think of one long stretch of small wire, never varying in size, and carrying one quantity of current.

112.—At first thought this seems like a very nice way of transmitting current, and the circuits seem so simple and cheap; but when the circuit is departed from and the generators and loads are considered, the problem becomes very complex.

113.—The multiple circuit is a little more difficult to understand to commence with, but as a person learns of it and uses it, the whole thing becomes attractive.

114.—The ease and simplicity with which the generators can be made to work on these circuits with varying loads is remarkable. The way in which lamps and motors can be wired on these circuits without interfering with other lamps and motors on the same circuit is also remarkable.

115.—With a series circuit if the wire comes out of the binding post of a lamp or motor the whole circuit is shut down, and all the customers have to wait until the trouble is looked up.

116.—With the multiple circuit any customer can pull down all the wiring in his place, and it would have no effect upon others on the same circuit.

CHAPTER XV.

TWO-WIRE SYSTEM.

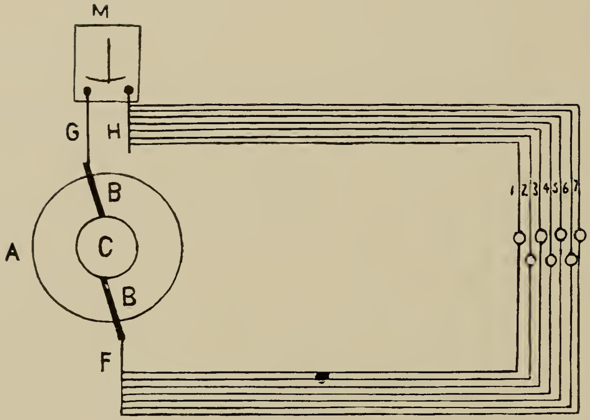

FIG. 5.

117.—By way of illustration we will consider that in Fig. 5 A is the armature of a dynamo, C is the commutator of the same machine, and that attached to B and B, the brushes, are two large wires, one, F, extending downward, and the other, G, extending up to the ammeter M, and then down to H. Now if we were going to put our lamps in series they would be arranged like Fig. 6; after leaving the ammeter the lamps would be strung along in a string as represented, same as the arc-lamps as illustrated under No. 56, but we are not going to put them in series; we are going to put them in multiple, as that is the best.

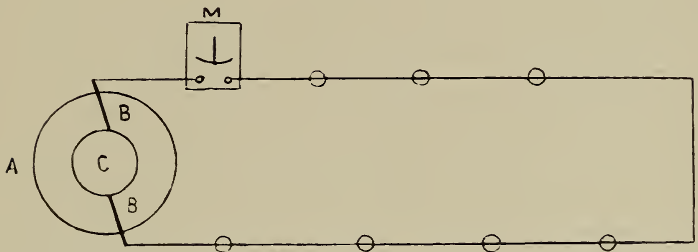

FIG 6

118.—We commenced at the large wire, H, and run out to lamp No. 1 and then back to the wire F, and since we have 114 volts at the machine and the pressure is on, and the lamps connected up, if we turn on the current at the key in the socket the lamp burns. The wire, we will consider, is 115178 circular mils in area and 1,000 feet long from wire H back to wire F, Fig. 5, just large enough to carry ½ ampere with four volts loss; hence we have 110 volts at the terminals of the lamps.

119.—We want to use another lamp in the same room. Well, what are we to do? No. 1 circuit is just large enough to carry lamp No. 1. We will go back to the large wire and run circuit No. 2, and put in lamp No. 2, same length of wire and same size. We wire up lamps 3, 4, 5, 6 and 7 all in the same way, and when they are all turned on we have seven lamps of 110 volts at their terminals, hence we have a pretty nice light. Some one will say, "Why, it is not customary to run a circuit for each and every lamp, is it?" We say "Yes," on a multiple system a circuit is run for each and everything that is wired in; each circuit must go right back to the dynamo.

120.—"But," a person will say, "that is nonsense, we know better." It is true just the same, there must be a metal circuit of some kind for each piece of apparatus or lamp that goes on a multiple circuit. It is not necessary that all these circuits should be a wire by themselves like we illustrated in Fig 5. They can all be combined in one bundle of wire and be run like the circuit in Fig. 7.

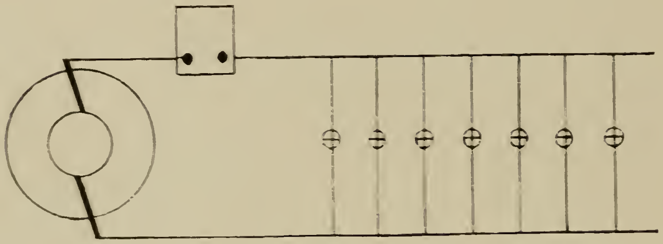

FIG 7

121.—Here we will consider that we have combined the seven wires of the circuit in Fig. 3, and have seven circuits in one bundle; hence if the lamps are the same distance from the machine there will be the same loss, since there is the same amount of copper carrying the current for the seven lamps.

122.—We have considered to some extent the multiple circuit, and now we will compute the wire for the mains of an incandescent circuit 1,000 16-candle-power lamps, the lamps to be put in one large building just 3,000 feet from the dynamo or station. This will mean 6,000 feet of wire large enough to carry current for 1,000 incandescent lamps, each lamp to take ½ ampere when burning; hence we must arrange to lead away 500 amperes of current.

123.—Since the distance is quite great for this kind of a circuit we will decide on eight volts drop, hence our machine will have to work at 118 volts pressure. On consulting a wiring table we will find that we will have to use the No. 0000 wire, B & S. gauge, for 50 lamps at this distance. No. 0000 wire has a resistance of .051 ohms to the thousand feet. This multiplied by six, since we have got to have 6,000 feet of circuit, gives us .306 ohms; .306 ohms multiplied by 25 amperes—the current that 50 lamps will take—equals 7.65, or very nearly the eight volts.

124.—We learned farther back that ohms multiplied by amperes gave the voltage necessary to make the amperes of current flow through the ohms resistance.

We have demonstrated that it will take a 0000 wire for 50 of our lamps; hence for 1,000 it will take 1,000 divided by 50 equals 20, or twenty 0000 wires. There are 211,600 circular mils in one No.

0000 wire; hence for twenty of them we will get a circular millage of 20 times 211,600 or 4,232,000 circular mils.

125.—No. 0000 wire weighs 639.33 pounds to the thousand feet, and since our circuit is 6,000 feet out to the building to be lighted and back, we will have to multiply this by six, which gives us 3835.98 pounds for one of our 0000 circuits, and since we must have twenty of these, we multiply again by 20 and get 76,719.60 pounds or about 38 tons, of 2,000 pounds, of wire for a circuit of only 1,000 lamps.

126.—We see at once that this will not do, as the copper will cost too much, and we commence to look up some other method.

127.—If we were using water and the cost of our energy was small we might use larger dynamos and put the pressure up to 140 volts, and waste 30 volts times 500 amperes or 15,000 watts of energy in the circuit when the lights are all on. This would reduce the size of our copper to a No. 3 wire B. & S. gauge for 50 lamps, and still we would have to use 159 pounds of No. 3 to the thousand feet x 6 x 20 which is 19,080 pounds, or about 9½ tons of bare copper.

128.—After having discovered how essential it was to put incandescent lamps on a multiple circuit pure and simple, the next problem that presented itself was decreasing the amount of copper for the circuits. One of the first things that suggested itself was to make the resistance of the incandescent lamps as high as possible. All the early incandescent lamps were run in series, hence the filament was large and had to carry the whole current of the machine or the series of batteries, as they were very often worked from batteries.

129.—It was soon found that the highest practical voltage was 110 or 120 volts. This makes the resistance of the 120-volt lamp, when burning, 240 ohms if it takes ½ ampere at 120 volts. This seems like a very high resistance for a strip of carbon so short as that in an incandescent lamp.

130.—To illustrate what a difference it would make in the amount of copper used, we will consider that we were going to use 220 instead of 110-volt lamps. The current would then be reduced to 250 amperes, just one-half of what it was before, and the E. M. F., or voltage, would be doubled, hence we would want 220 volts for lamps, plus eight volts for loss, or 228 volts.

131.—If we divide our lamps into 20 groups for convenience, as we did at first, we find that each group will take a No. 0 wire with a drop of 7.38 volts with the fifty lamps, or 12½ amperes to the group. Twenty No. 0 wires 6,000 feet long gives us about nineteen tons of copper, which is just one-half of what was used with the eight volts loss. By raising the voltage from 110 to 220 we could save over nineteen tons of bare copper on 1,000 lamps 3,000 feet from station; this is moving in the right direction, it is plain to be seen. It is supposed that the 220-volt lamps would take only $\frac{1}{4}$ ampere each.

132.—As stated previous to this, on reaching 110 volts this was about the limit of voltage for 16-candle-power lamps, and the reduction of copper had to be looked for in some other direction. The next step was the three-wire system, which is a good device patented in this country by T. A. Edison.

CHAPTER XVI.

THREE-WIRE SYSTEM.

133.—The study of the three-wire system is good to widen one's conception of the transmission of large currents.

134.—To work to advantage there should be at least two machines.

135.—We will consider that we have a town to light which will take a load of 1,000 lamps during the evening when the station has the most load to carry. We will compute the size of the feeders and connect them to the mains. To do this work it will take two 250-ampere machines of about 125 volts each. We will consider that the center of distribution is 3,000 feet from the station. We will arrange the machines and circuits as in Fig. 8.

136.—E and F are the two machines, A, B, C and D are the brushes on the commutators

137.—We will assume now that the machines have each a pressure of 110 volts at the brushes. We will put a heavy wire across from brush B to brush C, attach our wire Q to brush A, and our wire R to brush D.

138.—Now the machines are connected in series or their pressures are added together; hence we

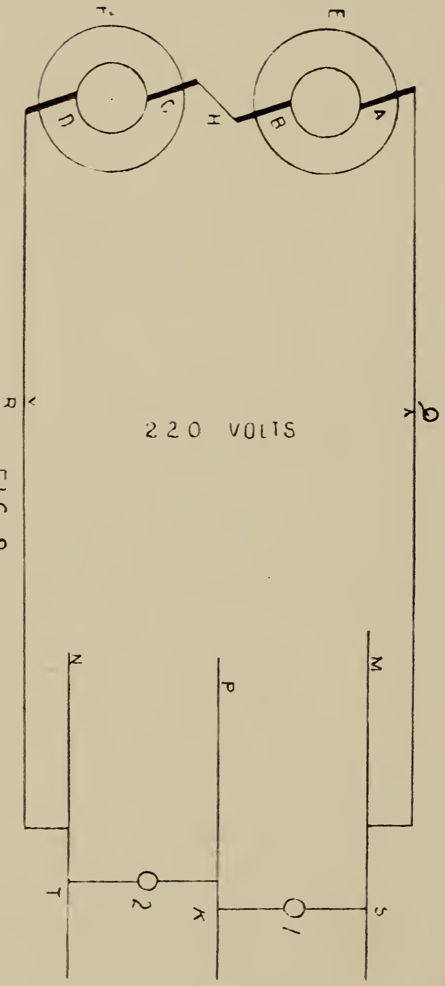

FIG 8

have between Q and R, 220 volts. One of the first questions that comes up is, "How are you going to work 110-volt lamps on a 220-volt circuit?" Well, it can be done very easily. We will put a lamp across from S to K, but of what use is that, since K is a dead wire? Well, we will put another lamp from K to T, then we have the circuit closed and two lamps in series across a 220-volt circuit, and since they are 110-volt lamps it will take just 220 volts to make them burn properly.

139.—The remark would come from some person at once: "Why, that seems like a very cumbersome device, and of what use is it?" It seems to sweep away the simplicity of the multiple system, but such is not the case; it dispenses with some of the very bad features of the multiple system, as it is used with two wires.

140.—In planning the wiring for our 1,000 lights 3,000 feet from the station we found that we must reduce the amount of copper somehow. We found what a great saving could be made in copper if we could use 220-volt lamps; well, some will see at a glance that this three-wire plan has done what we could not do by raising the voltage of the lamps, and still we can use the 110-volt lamps.

141.—We have only to carry out ½ ampere for two lamps, when as with the two-wire plan we would have to transmit out ½ ampere for each lamp.

142.—There is one quite serious drawback, and that is this: If lamp No. 1 is turned out, lamp No. 2 will also go out; that same old trouble that comes up in the series system. This is all very nicely arranged for and demonstrated in Fig. No. 9.

FIG. 9

There is a small third wire run out from H, or the wire connecting the two machines together, hence the term three-wire system, and this third wire connects with the circuit P. Now there are two independent circuits, and if there are ten or twelve lamps put on between wires M and P, and none between P and N, machine No. 1 carries them; and if there should be lamps turned on between P and N, and none on the other side, then machine No. 2 would do all the work.

143.—Some persons will see at once that we still have two circuits and no apparent saving in copper; but the third wire can be quite small, compared with the outside wires, as this third wire has only to carry the difference of loads between the two sides, and the wiring can be so carefully done that the load of lamps will go on both sides almost alike, hence there will be no current to speak of in the third wire.

144.—In practice the third wire is put in almost as heavy as either of the other two, then if anything should happen to one of the main wires the third wire would carry half the load with the other main.

145.—There is another good reason why the third wire should be almost equal in carrying capacity to the outside wires, and that is this: During the hours when the load is light, the whole system of wiring in a town or small-sized city can be connected up as a simple two-wire system, and the whole load carried by one small machine, and thus save the wear and tear on a part of the machinery and reduce the consumption of coal.

146.—By referring to Fig. 10 it will be seen that

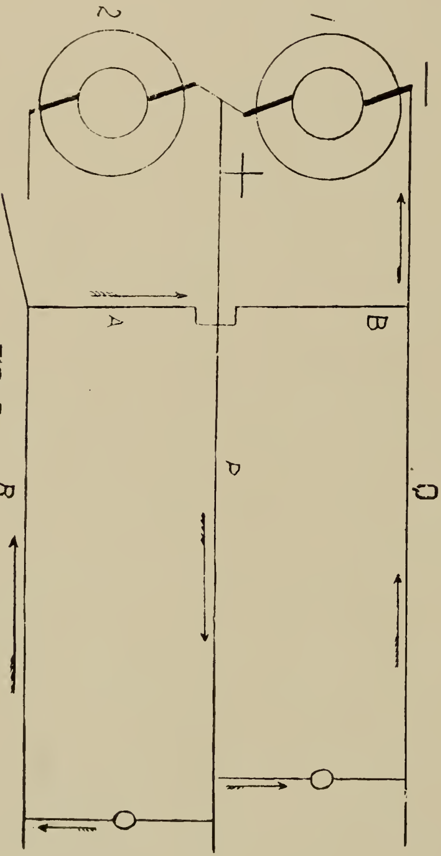

FIG. 10

machine No. 2 is cut out from its circuit and a wire A B put across from Q to R, which makes one main out of Q and R and another out of P, or the third wire. Under these conditions if the third wire, or P, is of proper size one machine can carry quite a load before the loss through P gets excessive.

147.—In small stations where this is put in practice there is a change-over switch used, which enables a person to make the change very quickly, so as not to leave the lamps out for any length of time.

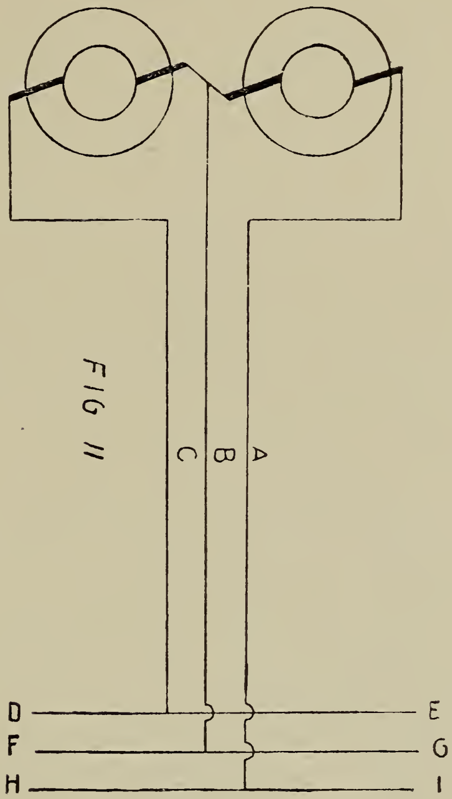

FIG 11

148.—Thus far we have been trying to get some knowledge of the fundamental principles of the low-pressure multiple systems of wiring. Now we will try and give this knowledge a little exercise, and add to it a little strength.

149.—We have not computed the feeders for our 3,000 lamps, and this we will try and attend to now.

150.—In Fig. 11 we have our two machines of 250 amperes each, and will run three wires, A, B and C, that we will call feeders. These connect the machines with the mains D E, F G, and H I A is connected to main D E, B to main F G, C to main H I.

151.—We want to compute the sizes of mains for a drop of not less than three volts from the point where the feeder comes into the main, to the point where the last lamps are taken off out near the end. This drop of three volts is to take place when the whole load of 250 amperes is passing through the feeders and mains.

152.—The feeders, which are 3,000 feet long from the machine to the mains, we will estimate copper for, so as to have a loss of 16 volts.

153.—The center of distribution is where the feeders connect with the mains. In this case at the point on the mains directly out from the station. if the center of the load was going to be on one side or the other of this point, the feeders would need to run up or down the street to that center.

154.—The question as to why 16 volts drop in the feeders and only 3 in the mains will suggest itself to some persons. The reason is this:

We are to tap on lamps all along the mains, and never want more than three volts difference in the feeders between any two points where lamps are tapped on. We don't care to tap lamps on the mains, as we want to make the drop in them excessive when the load is on, so as to save the expense of putting in so large copper.

155.—From our former figures we know that we want about a No. 3 wire, B. & S. gauge, if we divide the circuit into twenty parts, as we did before. No. 3 wire has a resistance of .205 ohms to the 1,000 feet, and this multiplied by six, since it takes six thousand feet out and back, will give us .1230 ohms for one of our circuits; and a twentieth of our current now is 250 divided by 20, or 12½; 1.23 ohms multiplied by 12½ amperes current would give us 15.37, or a little less than 16 volts drop.

1,000 feet of No. 3 wire, B. & S. gauge, weighs 159.03 pounds, hence 6,000 feet will weigh 954,18, and this multiplied by 20, the number of wires run, will give us 1908.60, or a little over 9.5 tons.

156.—We don't mean that it would be advisable to run twenty No. 3 wires, this would hardly be practicable, but this is a good method to use in computing wire sizes where we have a case similar to this we are studying, since it keeps our quantities small and makes them easy to handle; and when we get a wire selected for a part of the load we can multiply by the number of divisions and get the size wire necessary to do the work alone. If the wire be very large, when the manufacturer gets the order he will arrange the strands so as to get the proper number of circular mils.

157.—Suppose that we found that we wanted a wire to carry a certain amount of current with a certain drop or loss. With a circular milage of 23, 116 or very near this size, the manufacturer would, on referring to tables that he might have, find that he could use five No. 14 wires B. & S. gauge to make up the wire ordered. These he would bundle together and put on the insulation. If no insulation was wanted they could be put in wire-rope shape and used just the same.

158.—For so small a wire as 23,116 circular mils, if the wire was not ordered stranded, the manufacturer might ship in one solid wire, but for very large wires similar to what we have been computing, they would have to be stranded or they could not be handled very well.

159.—To get back to our circuit of twenty No. 3 wires B. & S. gauge, one No. 3 wire has in it 52,634 circular mils, and 20 would have twenty times this amount, or 1,052,680 circular mils, which would make a wire about as large as most of the mills could turn out with insulation upon it. This would be quite easily strung in a subway, but would want a good stiff pole line to hold it properly, and would necessitate having a good man to superintend putting it up.

160.—In Fig. No. 12 we have a plan of a three-wire system similar to the way that it might be installed in some town where the load was not too far from the station. We will consider that the distance from the station or machines Nos. 1 and 2 to the

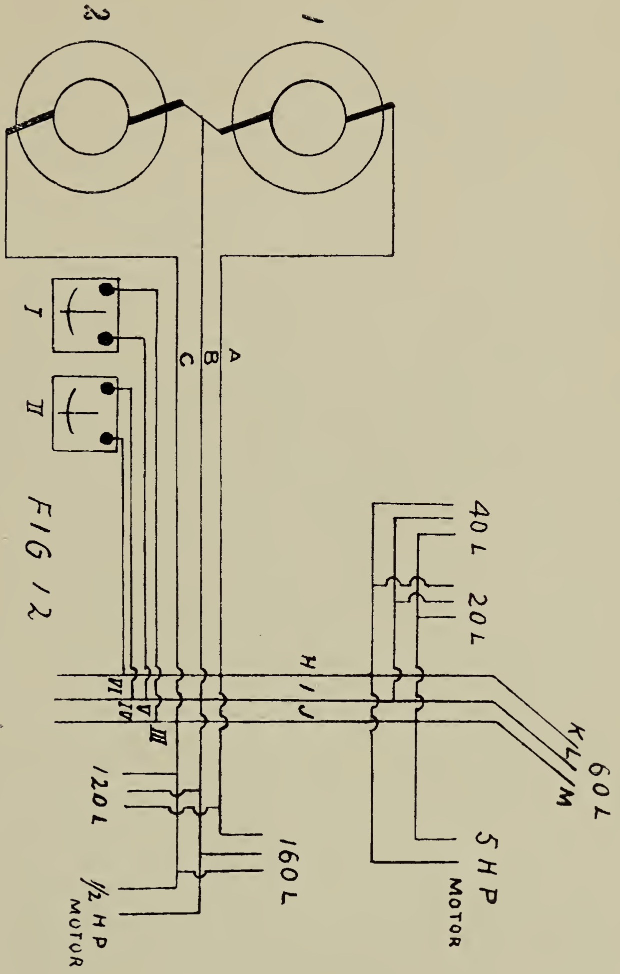

FIG 12

mains H, I and J is 3,000 feet. The machines we will consider are each 250 ampere and 120 volt.

161.—We will also consider that we are to wire up just one half of the load with motors and lamps, but put in the feeders and mains large enough for the whole load.

We will allow for 16 volts drop in our feeders with the full load. Dividing our 250 amperes by 5 will give us 50 amperes, which is more convenient to work with; 1,000 feet of No. 0000 wire has a resistance of .051 ohms, and this multiplied by 6, since there are 3,000 feet of wire out and 3,000 feet back, will give us .306 ohms, and this multiplied by our 50 amperes gives us 15.3 or the number of volts necessary to force the 50 amperes of current through the 6,000 feet of No. 0000 wire, which is very nearly the 16 volts loss that we concluded to allow.

162.—Then we are to understand that the two outside wires of our feeders must be equivalent in size to five 0000 wires, and we will put in copper equivalent to two 0000 wires for our third wire.

163.—In our feeders we now have arranged for twelve 0000 wires 3,000 feet long, or 36,000 feet of 0000 wire which has a weight of 639.33 pounds to the thousand feet. This means 23,015 pounds or 11.5 tons of 2,000 pounds each. The feeders A, B and C unite with the mains at H, I and J. The little loop indicates where the wires cross each other.

CHAPTER XVII.

MAINS, FEEDERS AND SERVICE WIRES.

164.—Our mains H, I and J we will consider are 1,000 feet long from one extreme to the other, or 500 feet each side of the point near I, or where the two third wires meet. We wiil put the load only on one end of the mains, and consider that the other end is to be a very near duplicate.

165.—Now there are many things here to be observed. Right at the point where the feeders meet the mains, we take off a set of auxiliary mains to to run up another street, and on these auxiliary mains we have wired up 160 plus 120 lamps, equals 280 lamps, 70 amperes plus 4½ amperes for a one-half-horse-power motor, which would make 74½ amperes that the first set of mains will not have to carry; 74½ taken from 125—the one-half load we were going to wire for—will give us 50½ amperes to carry out in the direction of the load that we have been putting on.

166.—The first tap is 300 feet, and here there is a five-horse-power motor tapped off on one side, taking about 20 amperes with full load, and a set of auxiliary mains on the other side of the street taking off 60 lamps or 15 amperes. This will make 20 plus 15 amperes, or 35 amperes, plus 15 amperes or 50 amperes that have got to be carried to this point. You may ask, "Why speak of the 15 amperes here for the lamps on the end of the circuit" but you must recollect that the mains have got to carry it even if it be not tapped off until we get farther along the street.

167.—Then we have 50 amperes that have got to be carried 300 feet with not more than three volts loss, since three volts loss in the mains is what we are to confine ourselves to.

168.—No, this is not right, since we have got to compute our copper for a drop of only three volts for our 60 lamps on the end of the line, and that is 200 feet farther. Now we have a puzzler, but it is quite a simple thing if we go at it right.

169.—For the present we will drop the 60 lamps on the end of the circuit and compute our copper for the 35 amperes to be carried 300 feet.

170.—A No. 1 wire has a resistance of .129 ohms to the thousand feet, and we want to use 300 feet twice, or 600 feet.

171.—600 feet is .6 of a thousand; so we multiply .6 by .129 and get .774, and this multiplied by our 35 amperes gives us 2.7 volts; this is very nearly the right size of bare copper.

172.—Now we have 15 amperes to be carried for 500 feet from the feeders; this means 1,000 feet of wire to carry 15 amperes with a loss of 3 volts.

173.—A No. 3 wire, B & S gauge, has a resistance of .205 ohms to the thousand feet, and this .205 ohms multiplied by our 15 amperes gives us three volts, hence No. 3 wire is what we want.

174.—This would necessitate running two circuits, or four wires, along 300 feet of our line and would take 151.72 pounds No. 1, and 159 pounds No. 3 B. & S. gauge, in all 310.72. For so short a distance it might be better to run only one wire, which would necessitate using more copper.

175.—By putting in only one circuit we would have to carry the whole 50 amperes in one wire for 300 feet, and by using No. 00 wire we would get a loss of 2.43 volts, or very nearly 2½ volts, and then we would have to run as large as a No. 00 wire the balance of the 200 feet, since we have only ½ volt left to keep with our 3 volts loss. By using a No. 00 wire for the balance of the way we would lose .48 volts for the 15 amperes.

176.—Running No. 00 wire the whole distance would necessitate the use of 1,000 feet of it, which would weigh about 402 pounds without any insulation, as compared to 310.72 pounds with the two circuits. For a longer distance the two circuits would be better if we held close to the three volts loss.

177.—Examples:

[*a*] If the auxiliary mains and service wires are to have a drop of two volts with all the lamps on, and it is 100 feet from the mains to the service wires running to the 20 lamps and 60 feet from this

point to where the service for the 40 lamps tap off, and the service wires in both cases are 20 feet long, or in other words it is 20 feet from the auxiliary mains to the branch or main blocks just inside the building, what size copper will have to be used in the auxiliary mains, from the mains out to the tap for the 20 lamps, and from the tap for the 20 lamps to the tap for the 40 lamps, and what size bare copper in each set of service wires?

[*b*] If on the ends of the mains at E, F and G we have to run the service wires 100 feet long to reach the 60 lamps, what size bare copper will it be necessary to put up so as to have one volt loss with the whole number of lamps on?

[*c*] With all the lamps on and taking the amount of current estimated that they were to take, and the motors running, each taking their full load estimate of current, will there be any current in the third wire passing back to station, and if any, how much?

178.—Some persons may not see clearly why the five-horse-power motor is connected onto the two outside wires. One good reason is because the five-horse-power motor can be built for 220-volt current very easily. Another reason is, if the motor was tapped on between the main and the third wire, that it would throw the load out of balance, and make quite a large current flow through the third wire.

179.—If it is better to put the five-horse-power motor from main to main, why put the ½-horse-power motor from main to third wire? One reason is that a ½-horse-power is cheaper to build for 110 volts than for 220, and another reason that it will handle easier on a 110 than on a 220-volt circuit.

180.—At the points III, IV, V and VI on the mains and third wire are small wires attached, and at the other end of these wires are pressure indicators I and II, placed at a convenient place in the station, so that the person in charge can see what the pressure is at the mains. This arrangement is used in many places, and these small wires running back are called pressure wires.

181.—With our three-wire system the pressure at the machines would vary between the outside wires, or the feeders, from 220 volts with a very small load, to 232 volts with a full load, and between the same feeders and the third wire the pressure would vary from 110 volts, with no load, to 116 volts, with a full load.

CHAPTER XVIII.

ALTERNATING CURRENTS.

182.—Some of us may think that so much space devoted to the low-pressure three-wire system is hardly right, when almost all the town and city lighting is done with a higher pressure, and with an alternating current.

183.—Right here we might say that the circuits of a thousand-volt alternating current are all arranged on the multiple system, but since the pressure is so much higher, the wiring is simpler since much lighter wire can be used.

184.—By way of illustration as to how much less copper is used in practice with the alternating current, we will compute the size of wire that is necessary to carry current at 1,030 volts pressure, up to the point where our feeders meet the mains in Fig. No. 10.

185.—Instead of 16 volts loss as adopted in our three-wire system, we will use up 30 volts, and consider that we are going to use 100-volt lamps in place of 110-volt as used in the other system.

186.—With the 1,030 volts we will consider that we are to use one machine and two wires.

187.—Some one will say at once that "30 volts loss is terrible. We demonstrated this before: it takes so much energy to force the current through the wire." At first thought this seems true, but on reflection one finds this is not the case.

188.—With the 110-volt circuit we lost 30 volts out of 110. You see that 30 taken from 110 reduces it very much, but 30 taken from 1,000 don't make much impression upon it.

189.—If we used 100-volt lamps in our two-wire system, and computed our mains for three volts loss, it would be the same as a thousand-volt circuit with 30 volts loss.

190.—The 100-volt circuit we would have to make 103 at the machine, and the 1,000-volt circuit 1,030. It is plain that 1,030 divided by 10 would give us 103, or we can make ten 103-volt circuits out of 1,030 volts. Now we can plainly see what advantage the high pressure is; we have 30 volts to lose in the circuit, and it don't mean very much energy. Some very bright fellow will conclude at once that we are wrong, since 30 volts loss is just so much loss, be it in a 1,030-volt circuit or in a 140-volt circuit. Such would be the case if the quantities of current were the same, but they are not, which we will now demonstrate.

191.—A good 110-volt 16-candle-power lamp would possibly take a little more than ½ ampere in most cases, but for convenience we will consider that our 16-candle-power 100-volt lamps are going to take ½ ampere each. This will make 500 amperes of current that will be used at the point where our transformers are used to transform the current down from 1030 to 103 volts.

192.--The primary current, or main current, of 1030 volts will have only one-tenth the amperage, since the pressure is ten times as high. One-tenth of 500 would give us 50, hence we have only to use 50 amperes in the high pressure wires to carry energy for 1,000 16-candle-power lamps. Fifty amperes multiplied by 30 volts gives us 1,500 watts or about two-horse power, which, you see, is very small compared to our 30 volts loss with the two-wire system.

193.—We will try a No. 0 wire for our mains. No. 0 wire has a resistance of .102 ohms to the thousand feet, and 6,000 feet would have .102 ohms multiplied by 6, or .612 ohms, and this multiplied by 50 amperes would give us 30.600, or just a little more than 30 volts.

194.—It is plain that No. 0 wire is large enough, 6,000 feet of which will weigh 1.854 pounds without any insulation. With the three-wire system it takes over eleven tons with a very heavy drop to do the same work. The saving in copper is plain to be seen.

Gauge, Diameter, Weight, Length and Resistance of Pure Copper Wire.

American or Brown & Sharpe Gauge.	Diameter.	Area.	Weight, Sp. Gr.--8.889.		Length.	Resistance of Pure Copper at 75° Fahrenheit,		
No.	In Mils.	Circular Mils.	Grains per Foot.	Lbs. per 1,000 Ft.	Feet per Pound.	Ohms per 1.000 Ft.	Feet per Ohm.	Ohms Per Pound.
0000....	460.000	211600.00	4475.33	639.33	1.56	.051	19605.69	.0000798
000....	409.640	167805.00	3549.07	507.01	1.97	.064	15547.87	.000127
00....	364.800	133079.40	2814.62	402.09	2.49	.081	12330.36	.000202
0....	324.950	105592.50	2233.28	319.04	3.13	.102	9783.63	.000320
1....	289.300	83694.20	1770.14	252.88	3.95	.129	7754.66	.00051
2. ..	257.630	66373.00	1403.79	200.54	4.99	.163	6149.78	.000811
3....	229.420	52634.00	1113.20	159.03	6.29	.205	4876.73	.001289
4....	204.310	41742.00	882.85	126.12	7.93	.259	3867.62	.00205
5....	181.940	33102.00	700.10	100.01	10.00	.326	3067.06	.00326
6....	162.020	26250.50	555.20	79.32	12.61	.411	2432.22	.00518
7....	144.280	20816.00	440.27	62.90	15.90	.519	1928.75	.00824
8...	138.490	16509.00	349.18	49.88	20.05	.654	1529.69	.01311
9....	114.430	13094.00	276.94	39.56	25.28	.824	1213.22	.02083
10...	101.890	10381.00	219.57	31.37	31.88	1.040	961.91	.03314
11....	90.742	8234.00	174.15	24.88	40.20	1.311	762.93	.05269
12 ...	80.808	6529.90	133.11	19.73	50.69	1.653	605.03	.08377
13....	71.961	5178.40	109.52	15.65	63.91	2.084	476.80	.13321
14...	64.084	4106.80	86.86	12.41	80.59	2.628	380.51	.2118
15. ..	57.068	3256.70	68.88	9.84	101.63	3.314	301.75	.3368
16....	50.820	2582.90	54.63	7.81	128.14	4.179	239.32	.5355
17....	45.257	2048.20	43.32	6.19	161.59	5.269	189.78	.8515
18....	40.303	1624.30	34.35	4.91	203.76	6.645	150.50	1.3539
19....	35.390	1252.40	26.49	3.78	264.26	8.617	116.05	2.2772
20....	31.961	1021.50	21.61	3.09	324.00	10.566	94.65	3.423
21...	28,462	810.10	17.13	2.45	408.56	13.323	75.06	5.443
22....	25.347	642.70	13.59	1.94	515.15	16.799	59.53	8.654
23....	22.571	509.45	10.77	1.54	649.66	21.185	47.20	13.763
24 ...	20.100	404.01	8.54	1.22	819.21	26.713	37.43	21.885
25....	17.900	320.40	6.78	.97	1032.96	33.684	29.69	34.795
26....	15.940	254.01	5.37	.77	1302.61	42.477	23.54	55.331
27....	14.195	201.50	4.26	.61	1642.55	53.563	18.68	87.979
28...	12.641	159.79	3.38	.48	2071.22	67.542	14.81	139.893
29....	11.257	126.72	2.68	.38	2611.82	85.170	11.74	222.449
30....	10.025	100.50	2.13	.30	3293.97	107.391	9.31	353.742
31....	8.928	79.71	1.69	.24	4152.22	135.402	7.39	562.221
32....	7.950	63.20	1.34	.19	5236.66	170.765	5.86	894.232
33....	7.080	50.13	1.06	.15	6602.71	215.312	4.64	1321.646
34....	6.304	39.74	.84	.12	8328.30	271.583	3.68	2261.82
35....	5.614	31.52	.67	.10	10501.35	642.443	2.92	3596.104
36....	5.000	25.000	.53	.08	13238.83	431.712	2.32	5715.36
37....	4.453	19.83	.42	.06	16691.66	544.287	1.84	9084.71
38....	3.965	15.72	.34	.05	20854.65	686.511	1.46	14320.26
39....	3.531	12.47	.27	.04	26302.23	865.046	1.16	22752.6
40....	3.144	9.89	.21	.03	33175.94	1091.865	.92	36223.59